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ON THE THERMAL STRUCTURE OF THE ATMOSPHERE OVER AGRA

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Summary.—The paper contains a detailed analysis of the thermal structure of the atmosphere over Agra based on the results of sounding balloon ascents carried out during the years 1929-38. The vertical distribution of lapse-rate with height in the different months of the year has been considered at some length on the mean as well as by a study of the frequency of occurrence of different values of lapse-rates at various heights from 0·5 to 26 gkms. In the lower troposphere, a level of minimum lapse-rate is noticed in all the months which lies between 1 and 2 gkms. in the winter months and between 5 and 6 gkms. in the summer months. Above this level, the lapse-rates generally increase with height in all the months, but the increase stops abruptly at about 11 gkms. in the months November to April. In these months, the lapse-rates are generally smaller above 11 gkms. and change sign between 16 and 17 gkms. In the months June to September, the lapse-rates continue to increase up to 14 gkms. and decrease rapidly above 15 gkms. Between 11 and 15 gkms. lapse-rates often approach and at times exceed 10°C/gkm. in these months. The close connection between the levels of sharp changes of lapse-rate and the levels of maximum frequency of inversions and isothermals in the troposphere is pointed out. It is found that the inversions and isothermals in the troposphere over Agra can be divided broadly into two systems. One system confined to the lower troposphere is present in all the months of the year. The other system confined to the upper troposphere is present in the months October to May but is absent in the months June to September.

Mean monthly temperatures at standard geodynamic levels up to 26 gkms. have been worked out with the help of the mean monthly lapse-rates and the mean monthly temperatures at 1 gkm. The annual range of temperature over Agra exhibits two maxima, one between 7 and 11 gkms. and the other between 17 and 19 gkms. Between 15 and 20 gkms., there is a reversal of seasons over Agra, the winter months being the warmest.

The sharp changes of lapse-rate, inversions and isothermals of the lower troposphere are essentially connected with anticyclonic subsidence in the winter months and with thermal convection, turbulence and clouds in the summer and monsoon months.

It is suggested that the radiative cooling of the "emission layer" discovered by Albrecht in the upper troposphere is the principal factor controlling the lapse-rates in the middle and upper troposphere over Agra during the months November to April, while condensation of water vapour and the consequent vertical convection from below is the main controlling agency during the months June to September. The emission layer is assumed to lie between 8 and 11 gkms. during the non-monsoon months and between 11 and 14 gkms. in the monsoon months. Barring the lowest levels affected by thermal convection and turbulence, the highest lapse-rates in all the months occur in and below the emission layer. Above the top of the emission layer, the atmosphere tends to attain radiative equilibrium. In the monsoon months, the convection currents penetrate some two or three gkms. above the top of the emission layer thereby destroying the radiative equilibrium at those levels. In the non-monsoon months, the sharp decrease of lapse-rate at about 11 gkms. marks the top of the emission layer. Above this height, the atmosphere tends towards radiative equilibrium. Meridional advection of air from lower towards higher latitudes, however, tends to upset this. The layer of decreasing temperatures above the lower transition in the months November to April appears to be the combined effect of advection and radiation.

* This paper was got ready for the press in April 1942 but could not be printed earlier due to war-time restrictions.

1. Introduction

In Vol. XXV, Part 5 of the Memoirs of the India Meteorological Department, Dr. Ramanathan has discussed the results of sounding balloon ascents made at Agra during the period July 1925 to March 1928. Since then, a considerable volume of data has accumulated as a result of the intensive and systematic soundings carried out from the Upper Air Observatory, Agra, which render possible a closer study of the thermal conditions obtaining in the free air over that station and their variations month by month. Such a study has been attempted in the present paper.

The present investigation is based on the results of 553 successful meteorograph ascents during the ten years 1929 to 1938. The data of the individual ascents have been published in the departmental publication "Upper Air Data, Part 14" for the years 1929 to 1935 and in "Upper Air Data, Part B" for the remaining period. The monthly distribution of ascents during the different years and the heights reached by the ascents during the different months are given in Tables I (*a*) and I (*b*).

TABLE I (*a*)

Distribution of Ascents

Year. \ Month.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Total.
1929 ...	5	6	3	6	3	2	3	8	7	7	5	6	61
1930 ...	2	2	4	6	5	6	1	4	4	5	5	5	49
1931 ...	19	21	18	17	12	9	7	3	2	5	5	...	118
1932 ..	1	6	2	3	3	3	4	6	7	5	4	6	50
1933 ...	5	4	4	3	3	...	1	3	5	7	4	6	45
1934 ..	10	3	2	5	4	1	1	2	4	2	1	5	40
1935 ..	4	2	1	1	2	8	6	2	2	1	3	3	35
1936 ...	8	3	4	1	..	5	6	4	3	3	3	4	44
1937 ...	3	6	1	2	1	2	6	7	2	6	1	4	41
1938 ...	10	...	2	...	5	13	10	16	3	4	5	2	70
Total ...	67	53	41	44	38	49	45	55	39	45	36	41	553

Table I (b)

Distribution of Ascents

Height (Gkm)	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
>20	21	11	8	14	10	11	6	10	7	16	12	11
20	27	17	22	23	12	15	7	12	8	23	19	15
19	35	26	27	29	18	21	11	16	16	31	22	22
18	41	29	34	34	24	29	16	26	23	34	24	30
17	49	32	35	38	26	32	23	28	27	38	26	33
16	51	36	37	39	28	33	28	33	27	39	29	34
15	52	36	38	39	31	33	29	37	29	39	30	35
14	53	36	38	39	31	34	32	39	30	39	30	35
13	57	40	38	40	31	34	32	39	31	40	30	35
12	58	41	38	42	32	36	33	39	32	41	30	35
11	60	42	38	43	32	36	35	40	32	41	30	35
10	60	44	39	44	32	36	37	43	33	41	30	35
9	61	45	39	44	32	37	37	44	38	43	30	35
8	61	46	40	44	32	37	37	45	34	44	30	36
7	61	48	40	44	33	37	40	47	38	44	33	37
6	62	52	41	44	38	42	41	48	38	44	33	37
5	67	52	41	44	38	47	42	50	38	44	35	39
4	67	53	41	44	38	47	44	52	38	45	36	40
3	67	53	41	44	38	48	44	53	39	45	36	41
2	67	53	41	44	38	49	45	55	39	45	36	41
1	67	53	41	44	38	49	45	55	39	45	36	41
Surface.	67	53	41	44	38	49	45	55	39	45	36	41

2. Mean Monthly Lapse-rates

From the published values of temperature at geodynamic levels the lapse-rates for the layers 0·5-1·0, 1·0-1·5, 1·5-2·0, 2·0-2·5, 2·5-3·0, 3-4, 4-5........26-27 gkms. were tabulated for the individual ascents. The mean monthly lapse rates for the various layers were then worked out by summing up the individual lapse-rates and dividing by the total number of observations in each layer. The values of the mean monthly lapse-rates thus calculated are given in Table II. The last column of this table gives the annual range of lapse-rates in the different layers. It will be seen that the variation of lapse-rate is least between 4 and 10 gkms. while above 10 gkms. and below 4 gkms. there is a sharp increase in the seasonal variation of lapse-rates. The table also brings out that on the mean, the lapse-rates between 4 and 10 gkms. do not exceed 8°C/gkm., while lapse-rates exceeding this value occur between 10 and 15 gkms. in the months June to September, and below 4 gkms. during the months March to June and October-November. Up to 4 gkms. the maximum values of lapse-rate occur during the months March to May and the minimum values in the winter or monsoon months. Between 4 and 10 gkms. the

lapse-rates on the mean are maximum in March-April and minimum during the period June-September. Above 10 gkms. and up to 17 gkms. the highest lapse-rates occur in July or August and the lowest values during the months December-March.

TABLE II

Mean Monthly Lapse-rates over Agra (°C/gkm.)

Layer (Gkm.)	Jan.	Feb	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Range
26-27		0·0		0·5		-1·5	·		-1·0		-1·5	-0·8	
25-26	-1·5	1·3				-2·0			-7·5		-1·5	-2·5	
24-25	2·0	-1·0		0·0	-2·5	2·7		-1·0	-4·7	-1·5	-3·0	-2·3	
23-24	3·0	3·0		0·5	-1·0	-1·7	3·0	-1·5	-3·7	-1·7	-3·4	-1·8	
22-23	-2·6	-2·0	-0·5	3·3	-2·3	1·8	1·0	-3·7	-3·4	-1·7	-4·1	-2·3	3·6
21-22	1·4	-3·6	-1·3	1·3	4·5	-2·9	5·0	-3·5	-3·5	-2·6	-3·6	-3·2	3·7
20-21	3·0	3·2	-3·3	4·9	5·8	-4·8	-3·6	4·7	-3·4	-3·2	-4·8	-2·6	3·2
19-20	-2·3	2·1	3·3	5·3	-5·5	-5·7	6·2	-5·0	-4·3	-4·7	-3·2	-2·3	4·1
18-19	1·9	-3·3	3·6	-3·4	4·9	-5·2	5·1	5·7	6·1	-5·1	-2·7	-2·6	4·5
17-18	0·9	0·8	-1·1	1·2	-1·5	-2·7	0·5	1·5	4·9	-4·1	-1·3	-1·1	5·4
16-17	0·4	1·4	1·9	2·5	2·3	2·6	3·8	1·9	1·1	0·4	1·2	0·4	3·4
15-16	2·5	3·3	3·2	4·2	5·3	6·7	7·2	6·2	6·6	4·0	3·0	2·2	5·0
14-15	3·6	3·5	5·1	5·5	6·0	8·0	8·7	8·7	8·4	6·3	4·3	3·2	5·5
13-14	3·7	4·2	5·2	4·9	7·0	8·5	9·4	9·2	9·2	7·4	5·8	4·1	5·7
12-13	3·8	4·3	5·2	4·9	6·7	8·5	9·0	9·1	8·7	7·6	6·6	5·8	5·3
11-12	5·4	5·7	5·4	5·7	6·8	8·3	8·5	8·7	8·4	7·7	6·7	6·3	3·6
10-11	6·9	5·4	5·2	6·4	6·7	7·7	8·0	8·3	7·8	7·8	7·6	6·7	3·1
9-10	7·1	6·3	6·6	8·0	7·2	7·3	6·9	7·4	7·4	7·3	7·0	7·1	1·7
8-9	7·0	7·0	6·5	7·9	6·8	6·5	6·1	6·8	7·2	7·1	7·4	7·1	1·5
7-8	6·9	7·3	6·9	7·6	7·0	6·0	5·7	6·0	6·3	6·8	7·1	7·0	1·9
6-7	7·1	7·1	7·9	7·4	6·9	4·9	5·5	5·5	5·6	6·3	6·9	7·2	2·5
5-6	6·9	6·8	6·8	7·0	5·8	4·4	4·9	5·0	5·9	5·6	6·9	6·4	2·6
4-5	6·2	6·2	7·2	7·6	6·8	6·0	5·4	5·4	5·3	5·7	6·7	6·5	1·9
3-4	6·2	6·3	7·4	7·6	8·2	6·9	4·8	4·8	5·2	4·9	5·2	5·8	3·4
2·5-3·0	6·1	6·2	7·3	8·5	8·8	7·3	4·9	4·4	5·4	6·4	5·6	5·5	4·4
2·0-2·5	5·1	6·6	8·4	9·0	8·8	7·6	5·7	4·9	5·8	7·5	5·2	4·8	4·2
1·5-2·0	4·7	6·2	8·5	8·8	8·4	7·6	5·5	5·3	6·2	8·1	5·6	4·8	4·1
1·0-1·5	5·0	6·6	8·9	9·0	8·1	8·3	7·0	6·3	7·3	8·6	6·7	4·1	4·9
0·5-1·0	7·6	7·9	9·1	8·9	9·0	7·7	7·0	7·0	7·6	8·9	9·2	7·1	2·2

During January there is a layer of well-marked minimum lapse-rate between 1 and 2 gkms. above which the lapse-rate increases with height at first rapidly and then slowly attaining a steady maximum value of about 7°C/gkm. between 5 and 11 gkms. Above

this height there is at first a rapid decrease of lapse-rate for the next two gkms. after which the decrease becomes gradual, the lapse-rate changing sign above 17 gkms.

Conditions in February are similar to those in January. It will, however, be seen that the minimum between 1 and 2 gkms. is less conspicuous than in the former month, while higher up the lapse-rate has commenced to decrease above 9 gkms.

With the advance of the hot season, the lapse-rate minimum between 1 and 2 gkms. is completely obliterated and in the month of March we find a layer of high lapse-rates extending up to 2·5 gkms. Above this height there is a sudden decrease of lapse-rate after which there is a gradual fall up to 10 gkms. A sharp decrease of lapse-rate again occurs at this height and thereafter the mean lapse-rate remains more or less constant up to 15 gkms. from which height there is a rapid fall to a negative value above 17 gkms.

From March to April the important change is the steepening of the lapse-rate in the lower levels, the layer of high lapse-rates now extending up to 3 gkms. An incipient layer of minimum lapse-rate is noticed between 4 and 6 gkms. above which there is a gradual increase to a maximum value of 8°C/gkm. between 9 and 10 gkms. The sharp fall of lapse-rate at 10 gkms. is even more conspicuous than in the previous month and the layer of steady lapse-rate up to 15 gkms. is still noticeable.

From April to May there are some important changes. While the lower layer of high lapse-rates now extends up to 4 gkms. with a flat maximum between 2 and 3 gkms. a pronounced minimum of lapse-rate has appeared between 5 and 6 gkms. Above the latter height the lapse-rate has a more or less steady value up to 14 gkms. from whence the fall to a negative value above 17 gkms. commences.

A fundamental change in the distribution of lapse-rates with height occurs from May to June. While in the lower levels up to 3 gkms. the lapse-rates are less than in the previous month, the lapse-rate minimum in the 5-6 gkm. layer (4·4°C/gkm.) is sharper and more conspicuous than in the month of May. The essentially new feature is, however, the gradual increase of lapse-rate from 6 gkms. to a maximum of 8·5°C/gkm. between 12 and 14 gkms. The lapse-rate commences to fall above the latter height and changes sign above 17 gkms.

The variation of lapse-rate with height is more or less identical in the monsoon months of July, August and September. A layer of high lapse-rate confined to the first 1·5 gkms. is followed by a layer of decreasing lapse-rates up to 4 gkms. A slight increase in lapse-rate between 4 and 5 gkms. followed by a minimum in the next gkm. layer is a feature in all the three months. Above 6 gkms. the lapse-rates increase with height reaching a maximum between 13 and 14 gkms. The lapse-rates begin to fall above 14 gkms., gradually up to 16 gkms. and rapidly thereafter, reaching a negative maximum of the order of —6°C/gkm. between 18 and 20 gkms.

The post-monsoon month of October differs from the retreating monsoon month of September in respect of the variation of lapse-rates with height. The lapse-rates up to 3 gkms. are higher than in the previous month. although in both these months the values

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decrease with height. A pronounced minimum of lapse-rate occurs between 3 and 4 gkms. after which the values increase with height and show a flat maximum between 10 and 14 gkms. Above the latter level the lapse-rate rapidly decreases with height to negative values above 17 gkms.

With the setting in of winter conditions in November the lower layer of high lapse-rates in the preceding month is very much contracted, while the sharp minimum between 3 and 4 gkms. is replaced by a layer of minimum lapse-rates extending from 1·5 to 4 gkms. Above this the lapse-rate increases up to 11 gkms. and commences to fall above that level.

The essential change from November to December is a contraction and lowering of the layer of minimum lapse-rate which now extends from 1 to 2·5 gkms. Lapse-rates gradually rise above this and attain more or less a steady value between 6 and 10 gkms. after which the values fall off with height.

In the region of negative lapse-rates above 17 gkms., we see that the lapse-rates have a negative maximum between 18 and 21 gkms. which is well pronounced in the months April to October. From the available observations which fall off rapidly in number above 20 gkms., it appears that above 22 gkms. the increase of temperature with height or negative lapse-rate is of the order of 2° to 3°C/gkm. for the next few gkms. in all the months.

Fig. 1 gives the curves of mean monthly lapse-rate against height for the individual months. *Fig. 2* gives the corresponding isopleth diagram.

3. Frequencies of Lapse-rates

In order to get a closer insight into the nature of the variation of lapse-rate with height in the different months, the lapse-rates for the different gkm. layers were classified as shown in the Tables III to XIV below. These are complementary to Table II and bring out many interesting features.

In the following discussion, we shall use the term "high lapse-rates" to mean lapse-rates greater than 7°C/gkm.

In the month of January high lapse-rates are common in the lowest layer 0·5-1·0 gkm. Between 1 and 2 gmks. we see a very large scatter of lapse-rates, all values ranging from −3°C/gkm. to 10°C/gkm. having been recorded in this layer. Above 2 gkms there is a gradual decrease in the scatter of the individual values and a general shift in the direction of high lapse-rates. The scatter is least between 5 and 7 gkms. and relatively smaller between 4 and 10 gkms. as compared with the levels above and below this layer. High lapse-rates occur at all levels up to 15 gkms., although their frequency is small above 12 gkms. The frequency of high lapse-rates exceeds 50 per cent between 0·5-1·0 and between 7-10 gkms. Above 11 gkms., the table shows that a sudden shift towards lower values takes place in the frequency distribution of lapse-rates. Above 17 gkms. the number of occasions on which positive lapse-rates have been observed is small.

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.)																	Total No. of Obsns.
	<−5·0	−5·0 to −4·0	−3·9 to −3·0	−2·9 to −2·0	−1·9 to −1·0	−0·9 to 0·0	0·1 to 1·0	1·1 to 2·0	2·1 to 3·0	3·1 to 4·0	4·1 to 5·0	5·1 to 6·0	6·1 to 7·0	7·1 to 8·0	8·1 to 9·0	9·1 to 10·0	>10·0	
25-26					1													1
24-25				1														1
23-24				1														1
22-23					1													4
21-22		1	1		3	1	2											8
20-21	2	5	4	5	1	2	1											20
19-20	2	3	4	6	5	2	2											24
18-19	1	3	12	5	4	5	2	2		1								35
17-18	1	3	3	9	6	5	5	6	3									41
16-17	1	2	4	1	7	4	11	9	4	5		1						49
15-16		1	1		1	5	5	11	5	10	6	4	2					51
14-15					1	3	3	6	10	6	8	9	1	2	1			50
13-14				1	2	2	5	6	4	7	10	4	6	1	1	1		50
12-13			3		2	2	3	4	8	11	3	5	4	4	3	1	1	54
11-12		1			1	2	2	3	2	3	7	5	8	8	7	1	1	51
10-11					1	1		1	1	1	6	6	10	10	5	9	1	52
9-10								2	1	2	3	8	7	11	7	8		52
8-9			1					2	1		3	6	7	15	12	2		49
7-8								1	2	1	4	5	7	8	17		1	46
6-7										8	2	7	14	12	9	1		48
5-6										2	5	10	11	19	5		1	53
4-5								1	1	6	12	11	15	16	4			66
3-4									5	2	8	14	18	11	4			66
2·5-3·0								7	2	5	10	9	13	12	7			65
2·0-2·5				1	1		2	3	7	6	6	9	15	7	3	1		61
1·5-2·0				1	1	3	4	4	7	7	6	5	14	2	2	2		58
1·0-1·5		1		1	2	3	3	4	5	1	7	10	10	6	6	2	1	62
0·5-1·0		1						1	1	4	3	3	7	7	11	11	2	51

January
January
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Sir
present Sir

Table IV—February

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.) < −5.0	−5.0 to −4.0	−3.9 to −3.0	−2.9 to −2.0	−1.9 to −1.0	−0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	Total No. of Obsns.
25-26				1		1												2
24-25			1			1	1											3
23-24		1	1	2														4
22-23			1	2	1													4
21-22	2	1	1	1	3													8
20-21	1	3	1	4	1													10
19-20	2	2	2	2	2	3	1		1									15
18-19	5	4	4	2	4	2	1	1										23
17-18	1		2	5	10	3	1	1	2	1	1							27
16-17		1		4	1	4	4	5	7	3	1	2						32
15-16				1	1	1	6	4	4	5	6	3	4	1				36
14-15				1		2	3	6	3	3	8	7	2					35
13-14					1	3	2	3	2	4	7	1	5	3	2			33
12-13			1		2	3		4	2	4	5	4	5	3	1	2		36
11-12		2	1		1	1		2		3	6	6	4	6	5	1		38
10-11		1		1	3	1	1	3	2		1	5	5	5	8	4		40
9-10			1					3	4	3	5	1	2	7	12	4		42
8-9						1	2		1	1	1	4	7	13	10	2		42
7-8									1	1	3	3	11	15	6	2		42
6-7												12	9	17	4			42
5-6									1		2	9	18	15	1	1		47
4-5										3	7	17	14	5	4			50
3-4						1		1	1	1	4	12	18	9	4			51
2·5-3·0							1	1	2	4	8	10	12	5	3	1	1	48
2·0-2·5							1	1	2	2	7	7	9	8	6	2		45
1·5-2·0					1	1		2	3	1	9	5	9	10	4	2		47
1·0-1·5					1	1	1	2	1	7	4	8	8	6	7	8	1	55
0·5-1·0							2		3	3		2	1	9	5	15	2	42

The broad features shown by the frequency table for February are similar to those of the previous month. We notice, however, that the scatter in the lower layer is not so pronounced as in January, while there is a definite shift towards higher values at all heights up to 2·5 gkms. Once again we see that the scatter of lapse-rates is least between 5 and 7 gkms. and that high lapse-rates are more frequent between 0·5—1·0 and 6-10 gkms. than at other levels. It will be seen that an increase in scatter and a displacement of the frequency figures in the direction of lower values set in above 8 gkms.

TABLE V- MARCH

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm).																	Total No. of Obsns.
	<-5.9	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	
25-26																		
24-25																		
23-24																		
22-23					1		1											2
21-22		1		1		2	1											5
20-21	2	1	2		1	2												8
19-20	4	5	2	5		5												21
18-19	7	6	5	3	3	2	1											27
17-18	2	3	4	1	9	5	4	3	2									33
16-17				1	3	6	4	6	6	2	2	4						31
15-16				1		1	3	6	8	4	7	4	1					35
14-15							1	1	4	6	6	12	3	2	1		1	37
13-14					1				4	5	8	5	12	2				37
12-13						1		3	2	5	5	7	8	6				37
11-12				1	1		2	2	2	4	3	6	5	5	2	3	1	37
10-11					3		3		4	3	2	6	6	6	3	2		38
9-10						1		1	1	5		5	7	8	6	4		38
8-9									2	3	2	7	8	9	5			36
7-8										2	1	8	9	6	7	3		36
6-7											1	9	9	11	3			36
5-6											4	6	15	8	5			38
4-5									1		3	4	12	15	6			41
3-4											2	7	9	8	8	2	1	37
2.5-3.0							1		1		1	5	5	8	8	3		34
2.0-2.5												4	5	8	9	10		36
1.5-2.0									2		1		4	7	14	11		39
1.0-1.5											1		3	5	17	10	3	39
0.5-1.0											1	1	1	8	9	8	6	35

In March high lapse-rates occur at all levels up to 12 gkms., their frequency being very large in the first 5 gkms. The scatter of lapse-rates in the lower levels is now much less than in February, but a definite shift in the frequencies towards lower values is noticeable above 2·5 gkms. The layer between 5 and 7 gkms. is characterised by least scatter in this month as well, while the individual lapse-rates show a rapidly increasing scatter above 8 gkms. The very pronounced scatter between 10 and 14 gkms. is noteworthy.

Table VI—April

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.) < −5·0	−5·0 to −4·0	−3·9 to −3·0	−2·9 to −2·0	−1·9 to −1·0	−0·9 to 0·0	0·1 to 1·0	1·1 to 2·0	2·1 to 3·0	3·1 to 4·0	4·1 to 5·0	5·1 to 6·0	6·1 to 7·0	7·1 to 8·0	8·1 to 9·0	9·1 to 10·0	>10·0	Total No. of Obsns.
25-26																		
24-25						1												1
23-24						1												1
22-23		1	3															4
21-22	2		2		1													5
20-21	6	4	1	2	1													14
19-20	11	3	2	4	2													22
18-19	8	3	2	8	4	2	1											28
17-18	2	1	6	7	4	2	6	4	2									34
16-17		1	1		2		6	7	7	6	2	4	1	1				38
15-16						1	1	4	6	5	8	5	8					38
14-15							1		2	9	6	6	7	4	3			38
13-14	1				1		1		2	5	4	15	3	2	2			36
12-13					2	1	3	1		4	7	10	4	3	1	2		38
11-12						1	3	4	2	2	8	5	8	2	3	2		40
10-11							2		2	5	2	6	7	7	5	3	1	40
9-10											1	6	5	9	9	11		41
8-9												1	11	13	13	3		41
7-8											1	2	13	16	7	3		42
6-7												2	18	13	8			41
5-6										1	2	8	16	8	3	4		42
4-5									1		4	8	9	14	6	1		43
3-4											5	1	7	6	12	3		34
2·5-3·0						1				1	2	2	1	5	14	9	2	37
2·0-2·5											1	1	3	6	17	12	3	43
1·5-2·0												2	1	13	15	10	2	43
1·0-1·5										1		1	2	8	17	9	4	42
0·5-1·0										1	1	1		9	9	11	4	36

The table for April brings out the large frequency of occurrence of high lapse-rates up to the first 5 gkms. in this month, the values often reaching and at times exceeding the dry adiabatic lapse-rate up to the first 3 gkms. We also see from the table that barring isolated instances, the lapse-rates up to 10 gkms. are greater than 4°C/gkm. at all levels in April. It is, however, seen that above 2·5 gkms. a sudden shift in the frequencies

towards low values takes place up to 6 gkms. Between 6 and 10 gkms. a shift in the opposite direction takes place, and this layer also shows the least scatter of lapse-rates. Above 10 gkms. a sharp change in the frequency distribution occurs, the lapse-rates showing a very large scatter at all higher levels, and particularly so in the three gkms. immediately above.

→ 1991/06/16
16%

TABLE VII—MAY

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/Gkm.) < -5.0	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to .	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	Total No. of Obsns.
25-26																		
24-25				1														1
23-24		1																1
22-23			1		1													2
21-22	2		2		1													5
20-21	6	4																10
19-20	9		1	1	1													12
18-19	6	6	2	3		1												18
17-18	1	1	5	2	4	5	5	1										24
16-17					1		4	9	5	4	2							25
15-16							2	1	2	3	5	5	4	2	2		1	27
14-15								1		1	10	7	7	1	4			31
13-14					1					3	2	4	6	4	8	1	2	31
12-13				1							2	5	12	3	8		3	30
11-12								1	2	1	2	2	8	13	5	1		31
10-11							1	1	2	1	3	2	3	[illegible]	5	2		30
9-10										1	2	3	9	7	4	1	1	26
8-9										2	1	1	8	9	4			27
7-8										1	2	6	7	6	4	1		27
6-7								1	1	1	1	8	7	10	2	2		28
5-6						1			4	2	3	9	5	6	3			33
4-5										2	3	8	10	7	7			37
3-4											1	1	2	6	16	2		28
2.5-3.0												2	3	9	9	9	3	35
2.0-2.5											2	1	2	5	14	12	1	37
1.5-2.0									1	1	1	2	3	9	11	8	2	38
1.0-1.5										3	2	2	2	7	18	2	2	38
0.5-1.0												1	3	5	16	4	3	32

While lapse-rates continue to be high up to the first 4 gkms. in the month of May, lower values are also occasionally encountered in this layer particularly between 1 and 2 gkms. A striking shift in the frequency figures towards lower values takes place above 4 gkms. which persists for the next two gkms. Although there is a tendency towards higher lapse-rates above this height, there is appreciable scatter at all levels, particularly between 10 and 12 gkms.

TABLE VIII—JUNE

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.)																	Total No. of Obsns.
	< −5.0	−5.0 to −4.0	−3.9 to −3.0	−2.9 to −2.0	−1.9 to −1.0	−0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	> 10.0	
25-26				1														1
24-25			1	1														2
23-24			1	2			1											4
22-23		1		1			1											3
21-22		2	3															5
20-21	3	4	3															10
19-20	10	3		1														14
18-19	9	4	5	2	1													21
17-18	8	3	3	3	3	1	2	2	1		2							28
16-17		2	1		1	1	3	1	5	2	6	5	3					30
15-16									2		4	4	5	12	1	1	1	30
14-15											1	1	6	10	7	3	2	30
13-14												1	3	9	13	5	1	32
12-13												1	2	10	10	8	1	32
11 12												2	3	12	13	3	2	35
10-11											1	1	6	17	8	1		34
9-10											1	3	12	13	5			34
8-9									1	1	1	9	14	8	1			35
7-8							1			1	8	11	7	8	1			37
6-7						1	3	2		4	9	10	4	3	1			37
5-6							1	4	5	10	9	8	2	3				42
4-5								1	1	5	6	15	5	7	1	2		43
3-4											8	5	8	7	5	1	2	36
2·5-3·0										3	5	4	13	10	8	4		47
2·0-2·5										1	5	10	7	5	11	9		48
1·5-2·0									2	1	5	5	5	10	14	3	1	46
1·0-1·5										1	4	1	10	7	9	7	5	44
0·5-1·0									1	1	3	3	4	7	4	3	3	29

High lapse-rates up to 3 or 4 gkms. are frequent in June, but lower values are more common than in the previous month. Above 4 gkms. there is a sudden shift of frequencies towards the side of lower lapse-rates, and this persists up to 7 gkms. Above 7 gkms. the frequencies shift towards the side of higher values. It will be seen that barring one or two isolated instances, lapse-rates less than 6°C/gkm. have never been noticed between 10 and 15 gkms., while between 12 and 15 gkms. lapse-rates can be as high as 10°C/gkm. or more. The frequencies show the least scatter between 8 and 15 gkms.

TABLE IX—JULY

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Rang of Lapse-Rates (°C/Gkm.)																	Total No. of Obsns.
	<-5.0	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	
25-26																		
24-25																		
23-24			1															1
22-23					1													1
21-22		1																1
20-21	1	2	1					1										5
19-20	5	1					1											7
18-19	5	1	1	2		1												10
17-18		1		1	3	2	2	4				1	1					15
16-17				1	1	1	1	2	3	3	2	5	1	3				23
15-16								1		1	1	3	6	10	2	2	1	27
14-15								1					1	11	6	5	4	28
13-14													1	3	12	8	8	32
12-13													1	9	7	11	4	32
11-12													3	12	11	4	3	33
10-11												1	5	15	10	2		33
9-10											2	2	19	9				32
8-9											2	18	12	5				32
7-8											6	24	4	1				35
6-7										1	13	19	4	1				38
5-6							1	1	1	5	17	12		2				39
4-5							1		1	4	11	10	5	4	1			37
3-4								2	3	8	13	9	8		1			39
2.5-3.0								5	3	7	11	10	7					43
2.0-2.5							1		3	3	14	9	7	5	1			43
1.5-2.0								2		15	7	7	7	2	2	2		44
1.0-1.5									1	4	6	8	7	5	5	5	1	42
0.5-1.0								1		2	2	4	5	5	5		1	25

TABLE X—AUGUST

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.) <-5·0	-5·0 to -4·0	-3·9 to -3·0	-2·9 to -2·0	-1·9 to -1·0	-0·9 to 0·0	0·1 to 1·0	1·1 to 2·0	2·1 to 3·0	3·1 to 4·0	4·1 to 5·0	5·1 to 6·0	6·1 to 7·0	7·1 to 8·0	8·1 to 9·0	9·1 to 10·0	>10·0	Total No. of Obsns.
25-26																		
24-25					1													1
23-24					1													1
22-23	1			1														2
21-22	1	1		2														4
20-21	4	2	3		1													10
19-20	4	5	1			1												11
18-19	11	2	2			1												16
17-18	5	3	8	5	3		3	1	1	1	1							26
16-17	1	1	1		3	2	3	1	3	4	6		2	1				28
15-16		1					1			4	4	4	6	3	4	4	2	38
14-15												1	2	8	15	5	5	36
13-14									1				1	5	11	10	10	38
12-13													2	5	19	7	5	38
11-12												2	2	8	17	6	3	38
10-11													6	18	12	2	2	40
9-10												5	15	17	5		1	43
8-9											1	11	20	9	2			43
7-8											9	18	12	2				41
6-7									1	1	15	19	8	1				45
5-6							1	1	1	4	23	11	3	1				48
4-5							1			2	14	17	8	1				43
3-4								1	3	6	19	11	1	2				43
2·5-3·0							1	4	10	13	14	2	6	1				51
2·0-2·5							1	2	3	13	20	7	4		2			52
1·5-2·0							1	2	4	9	12	14	6	5	1			54
1·0-1·5									2	8	14	7	8	10	3	2	1	55
0·5-1·0										3	3	7	5	9	5	1		33

The frequency distribution of lapse-rates is very similar in the monsoon months of July and August. High lapse-rates occur up to about 2 gkms., but the frequencies are comparatively small. From 2 to 8 gkms. lapse-rates seldom exceed 7°C/gkm., values as low as 3°C/gkm. being not uncommon between 2 and 4 gkms. The rapid increase and remarkable steadiness of the lapse-rates between 8 and 15 gkms. is noteworthy. Between 10 and 15 gkms., lapse-rates of 10°C/gkm. and more are quite common in both these months.

Table XI—September

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.) <-5.0	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	Total No. of Obsns.
25-26	1																	1
24-25	1				1													2
23-24		1	1															2
22-23	1			2	1													4
21-22	1	1		1		1												4
20-21		3	1	1	1													6
19-20	2	3		2														7
18-19	7	4	2	1														14
17-18	9	4	3		2	1		1		1								21
16-17		1	2	2	3	3	3	1	3	2	3		1	1				25
15-16								1		3	3	5	2	6	5	1		26
14-15												2	5	7	5	7	3	29
13-14													1	7	7	9	5	29
12-13												1	2	4	16	5	1	29
11-12													3	8	14	3		28
10-11													5	17	6	1		29
9-10												3	10	12	4	1		30
8-9											1	4	11	9	6			31
7-8									1	1	2	10	13	5	1			33
6-7									2	4	7	12	10	1		1		37
5-6							1	1	2	6	10	13	3	1				37
4-5								3	2	3	7	10	7		1	1		34
3-4									1	7	10	6	6	2				32
2·5-3·0		1				1		1	4	6	8	6	5	2	2	1		37
2·0-2·5								1	3	5	9	8	4	6	3			39
1·5-2·0									1	8	6	4	3	6	2	2		37
1·0-1·5										2	6	5	4	11	3	6		37
0·5-1·0									1	1	4	1	5	5	6	4	1	28

While showing a striking resemblance to July and August, the frequency table for September shows a greater percentage of high lapse-rates in the lower layers up to 3 gkms. Between 3 and 7 gkms. lapse-rates seldom exceed 7°C/gkm., while lapse-rates as low as 3°C/gkm. or even less are occasionally met with between 2 and 6 gkms. Above 7 gkms., the frequencies shift towards higher values as in the previous two months. Adiabatic and superadiabatic lapse-rates are most frequent between 12 and 15 gkms.

Comparing the frequency figures between 7 and 16 gkms. with the corresponding figures in the previous two months, we see a definite tendency for the downward extension of high lapse-rates. The remarkable steadiness of the values between 8 and 15 gkms. is again noteworthy.

Table XII—October

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/Gkm.) < -5.0	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	Total No. of Obsns.
25-26																		
24-25					1													1
23-24			1			1												2
22-23				2	1													3
21-22		1	1	2	2													6
20-21	1	3	5	4	3													16
19-20	7	6	5	3	2													23
18-19	12	9	5	1			1											28
17-18	11	8	5	1	2	1	1	2										31
16-17	1	4	1	5	3	4	3	4	6	2	3	1	1					38
15-16				1	2		1	2	7	5	5	4	6	1	1			35
14-15							1	1	5	2		3	10	9	3		1	35
13-14								1	2		2	3	6	8	7	6	1	36
12-13					1						1	6	4	8	9	7		36
11-12											1	4	6	16	6	5		38
10-11								1				1	8	12	13	1	1	37
9-10										1	1	2	12	14	6	1		37
8-9										1	2	5	11	14	5			38
7-8										3	4	2	10	11	6			36
6-7									1	2	6	8	11	7	3			38
5-6								1	2	7	6	10	5	5	2			38
4-5							1	1	1	7	5	9	8	7	1	1		41
3-4					2	1			3	3	8	10	3	4	1			35
2.5-3.0		1						2	3	3	5	3	6	6	8	2	1	40
2.0-2.5								1	1	1	2	8	5	9	11	5		43
1.5-2.0										2	2	2	4	14	17	3	1	45
1.0-1.5										2	1		3	15	13	6	5	45
0.5-1.0								1		2			1	5	12	9	4	34

In October high lapse-rates up to 3 gkms. are much more frequent than in September. Above this height, there occurs, as in the previous month, a definite shift of the frequencies towards smaller values for the next 3 or 4 gkms. It is also seen that high lapse-rates occur at all levels up to 15 gkms., but their frequency is least between 3 and 7 gkms. Above the latter height, there is a general shift of frequencies towards higher values. Although adiabatic lapse-rates occur between 12 and 14 gkms., their frequency is smaller

TABLE XIII—NOVEMBER

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/Gkm.) < -5.0	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	Total No. of Obsn.
25-26			1		1	1												3
24-25		1		2														3
23-24	2			1	2													5
22-23	2	2	2	1														7
21-22	1	2	1	2	1													7
20-21	5	3	3			1												12
19-20	2	4	5	2	1	1	1											16
18-19	2	4	8		1	3		2										20
17-18		6	2	3	5	2	1	2	3									24
16-17			1	2	3	2	6	3	3	3	2	1						26
15-16						1	2	9	6	7	1	2	1					29
14-15						1	1	2	7	4	7	4		3	1			30
13-14								1	2	3	8	5	6	1	2	2		30
12-13						1			3		1	4	5	9		2		29
11-12												4	6	6	7			28
10-11										1		2	5	10	5	2		25
9-10											1	2	4	5	8	1		24
8-9											1	3	3	13	3	1		24
7-8											1			6	7			24
6-7											1	5	8	8	2			24
5-6												7	12	8	3			31
4-5									1		6	6	11	8	1			~~33~~
3-4							1	1	4	1	8	5	6	1	2			29
2.5-3.0						1		5	2	2	7	4	2	5	3	1	1	33
2.0-2.5			1			3	2	1	1	4	7	2	2	5	4	2		34
1.5-2.0		1		1			1	1		6	5	7	3	1	5	3		34
1.0-1.5		1		1		1	1		2	2		2	6	5	12	3		36
0.5-1.0											1		2	6	10	7	5	31

than in September. Also compared to September, the frequency distribution at all levels between 8 and 15 gkms. in October shows a general shift towards smaller values.

Table XIV—December

Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.) < -5.0	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	Total No. of Obsns.
25-26				2														2
24-25			2		2													4
23-24			1	2	1	1												5
22-23	1			3			1											5
21-22	1	1	3	2	1	1												9
20-21	1	2	2	2	1	2												10
19-20	1	2		7	1	2	1											14
18-19	2	5	3	4	3	3		1	1									22
17-18	1	1	5	8	5	3	1	1	2	2	1							30
16-17			2	5	4	6	3	5	4	1	1	1						32
15-16		1		2	2	3	1	6	6	3	7	1			1			33
14-15		1	1	1		4	1	2	6	5	5	2	2	3				33
13-14						1	3	2	5	7	5	5		3		1		32
12-13							1	1	2	5	6	5	2	2	5	2	1	32
11-12								4		4	2	5	6	3	2	4	2	32
10-11								1		3	3	1	9	5	5	2		29
9-10						1			1	1	3	2	2	8	10	2		30
8-9										3	1	5	4	5	8	2		28
7-8									1		2	4	11	7	4	1		30
6-7										2		3	10	10	5	1		31
5-6										1	5	7	13	6	1			33
4-5									1	1	6	9	9	7	4	1		38
3-4									1	3	9	11	8	5	1			38
2.5-3.0							1	2	8	3	5	6	10	3	2		1	41
2.0-2.5			1			1		1	3	11	4	9	3	1			1	35
1.5-1 0		1					3	1	5	6	5	8	6	1	2			38
1.0-1.5		1	1	1	3	3	3	3	1	3	5	3	2	4	2	3	1	39
0.5-1.0					1		1		3	1	2	1	2	2	6	6	1	26

A pronounced scatter of lapse-rates between 1 and 4 gkms. is noticed in the month of November. High lapse-rates occur at all levels up to 15 gkms., but they are most frequent in the lower levels up to 3 gkms. and higher up between 7 and 13 gkms. Above 11 gkms., the frequency figures show a drift towards decreasing values.

The general features in December are more or less the same as those in January. Attention may be drawn to the large scatter of lapse-rate in the lower levels up to about 3 gkms. and the tendency for the occurrence of high lapse-rates in the layer between 7 and 13 gkms.

4. Seasonal Mean Lapse-rates and Percentage Frequencies of Lapse-rates

The year at Agra may be divided into four seasons:—

(1) Winter—December, January, February.
(2) Summer—March, April, May.
(3) Monsoon—June, July, August, September.
(4) Transitional—October, November.

TABLE XV—DECEMBER, JANUARY, FEBRUARY

Percentage Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.)																	Mean Lapse-rate.
	< -5·0	-5·0 to -4·0	-3·9 to -3·0	-2·9 to -2·0	-1·9 to -1·0	-0·9 to 0·0	0·1 to 1·0	1·1 to 2·0	2·1 to 3·0	3·1 to 4·1	4·1 to 5·0	5·1 to 6·0	6·1 to 7·0	7·1 to 8·0	8·1 to 9·0	9·1 to 10·0	>10·0	
22-23	9		31	38	15		8											-2·3
21-22	12	12	20	12	23	8	8											-2·8
20-21	10	25	18	27	7	10	3											-3·0
19-20	9	13	11	28	15	13	8		2									-2·3
18-19	10	15	24	14	14	12	4	5	1	1								-2·5
17-18	3	4	10	22	21	11	7	8	7	3	2							-0·9
16-17	1	3	5	9	11	12	16	17	13	8	2	4						0·7
15-16		2	1	3	3	8	10	17	13	15	16	7	5	1	1			2·7
14-15		1	1	2	1	8	6	12	16	12	18	15	4	1	1			3·4
13-14				1	3	5	9	10	10	16	19	9	9	6	3	2		3·9
12-13			3		3	4	3	7	10	16	12	12	9	7	7	1	2	4·5
11-12		2	1		2	2	2	7	2	8	12	13	15	14	12	5	2	5·5
10-11		1		1	3	2	1	4	2	3	8	10	20	17	15	12	1	6·4
9-10			1			1		4	5	5	9	9	9	24	24	11		6·8
8-9			1			1	2	2	2	3	4	13	15	28	25	5		7·0
7-8			1					1	3	2	8	10	24	25	23	3	1	7·0
6-7										4	2	18	27	32	15	2		7·1
5-6									1	2	9	20	32	31	5	1	1	6·8
4-5								1	1	6	16	24	25	18	8	1		6·3
3-4					1	1		1	5	4	14	24	28	18	6			6·1
2·5-3·0							1	7	8	8	15	16	23	13	8	1	1	6·0
2·0-2·5			1	1	1	1	2	4	9	13	12	18	19	11	6	2	1	5·6
1·5-2·0		1		1	1	3	5	5	10	10	14	13	20	9	6	3		5·2
1·0-1·5		1	1	1	4	5	5	6	5	7	11	11	13	11	10	9	2	5·3
0·5-1·0		1			1		3	1	6	7	4	5	8	15	18	27	4	7

Table XVI—March, April, May

Percentage Frequencies of Lapse-rates over Agra

Layer. (Gkm.)	Range of Lapse-rates (°C/gkm.)																	Mean Lapse-rate.
	< −5·0	−5·0 to −4·0	−3·9 to −3·0	−2·9 to −2·0	−1·9 to −1·0	−0·9 to 0·0	0·1 to 1·0	1·1 to 2·0	2·1 to 3·0	3·1 to 4·0	4·1 to 5·0	5·1 to 6·0	6·1 to 7·0	7·1 to 8·0	8·1 to 9·0	9·1 to 10·0	>10·0	
22-23		12	50		25		12											−2·3
21-22	27	7	27	7	13	13	7											−3·4
20-21	44	28	9	6	6	6												−4·8
19-20	44	15	9	18	5	9												−4·6
18-19	29	21	12	19	10	7	3											−3·3
17-18	5	5	16	11	19	13	16	9	4									−1·2
16-17		1	1	1	6	6	14	23	19	12	6	8	1	1				2·2
15-16				1		2	6	11	16	12	20	14	13	2	2		1	4·1
14-15							2	2	6	15	21	24	16	7	8		1	5·5
13-14	1				3		1		6	13	13	23	20	8	10	1	2	5·6
12-13				1	2	2	3	5	2	9	13	21	23	11	4	2	3	5·5
11-12				1	1	1	5	6	6	6	12	12	15	19	9	6	1	5·7
10-11					3		6	1	7	8	6	13	15	21	12	6	1	6·4
9-10						1		1	1	6	3	13	20	22	18	15	1	7·3
8-9									4	5	3	9	26	30	21	3		7·1
7-8										3	4	15	28	27	17	7		7·2
6-7								1	1	1	2	13	32	35	12	2		7·1
5-6						1			4	3	8	20	32	19	10	4		6·6
4-5									2	2	8	16	25	30	16	1		7·0
3-4											8	9	18	20	36	7	1	7·7
2·5-3·0						1	1		1	3	3	8	8	21	29	20	5	8·2
2·0-2·5											3	5	9	16	34	29	9	8·8
1·5-2·0									3	1	2	3	7	24	33	24	3	8·6
1·0-1·5									1	3	2	3	6	17	43	17	7	8·7
0·5-1·0										2	2	3	4	21	33	22	13	9·0

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TABLE XVII—JUNE, JULY, AUGUST, SEPTEMBER

Percentage Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-rate (°C/gkm.) < −5·0	−5·0 to −4·0	−3·9 to −3·0	−2·9 to −2·0	−1·9 to −1·0	−0·9 to 0·0	0·1 to 1·0	1·1 to 2·0	2·1 to 3·0	3·1 to 4·0	4·1 to 5·0	5·1 to 6·0	6·1 to 7·0	7·1 to 8·0	8·1 to 9·0	9·1 to 10·0	>10·0	Mean Lapse-rate.
22-23	20	10		40	20		10											−2·8
21-22	13	33	20	20		13												−3·4
20-21	26	35	26	3	6													−4·8
19-20	54	31	3	8		3	3											−5·4
18-19	52	18	16	8	2	8												−5·6
17-18	24	12	10	10	12	4	8	9	2	2	3	1	1					−2·3
16-17	1	4	4	3	8	7	9	5	13	10	16	9	7	5				2·2
15-16		1					1	2	2	7	10	14	16	27	10	7	3	6·7
14-15											1	3	11	29	27	16	11	8·5
13-14									1			1	5	18	33	24	18	9·1
12-13												2	5	21	40	24	8	8·9
11-12												3	8	30	41	12	6	8·5
10-11											1	1	16	49	26	4	1	8·0
9-10											2	9	40	37	10	1	1	7·2
8-9							1		1	1	4	26	40	22	6			6·7
7-8									1	1	17	43	25	11	1			6·0
6-7							2	1	2	6	28	38	17	4	1	1		5·4
5-6						1	2	4	5	15	36	28	5	4				4·8
4-5							1	3	3	9	24	33	16	8	2	2		5·5
3-4								2	5	14	33	21	12	7	4	1	1	5·4
2·5-3·0		1					1	6	10	16	21	12	17	7	6	3		5·5
2·0-2·5								2	5	12	26	19	12	9	9	5		6·0
1·5-2·0								2	4	18	17	17	14	13	10	4	1	6·1
1·0-1·5									2	8	17	12	16	19	11	11	4	7·1
0·5-1·0								1	2	6	10	13	17	23	17	7	4	7·3

any Questions bow you ?

Five Years play

please can you tell me?

Tables XV, XVI, XVII and XVIII give the percentage frequencies of lapse-rates at various gkm. steps from 0·5 to 23 gkms. in the four different seasons. The last column in each table gives the seasonal mean values of lapse-rate. The general features shown by these tables will be clear from the discussions in the preceding sections.

Fig. 3 gives a diagramatic representation of the seasonal variation of lapse-rates over Agra. In this figure, the percentage frequencies of different lapse-rates for the various layers are plotted as ordinates on the horizontal lines appropriate to the layers and the points are joined by a smooth curve. The scale is so chosen that the distance

Table XVIII—October, November

Percentage Frequencies of Lapse-rates over Agra

Layer (Gkm.)	Range of Lapse-Rates (°C/gkm.) < -5.0	-5.0 to -4.0	-3.9 to -3.0	-2.9 to -2.0	-1.9 to -1.0	-0.9 to 0.0	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	5.1 to 6.0	6.1 to 7.0	7.1 to 8.0	8.1 to 9.0	9.1 to 10.0	>10.0	Mean Lapse-rate.
22-23	20	20	20	30	10													-3.2
21-22	8	23	16	31	23													-3.1
20-21	21	21	30	14	11	4												-3.9
19-20	23	25	25	18	7	3	3											-4.1
18-19	29	27	27	2	2	6	2	4										-4.1
17-18	20	25	18	7	13	5	4	7	5									-2.9
16-17	2	6	8	11	9	9	14	11	14	8	8	3	2					0.7
15-16				2	3	2	5	17	20	19	9	9	11	2	2			3.5
14-15						2	8	5	18	9	11	11	15	18	6		2	5.3
13-14								3	6	5	16	12	18	14	14	12	2	6.6
12-13					2	2			5		3	15	14	26	20	14		7.2
11-12								1		3	6	12	18	33	19	7		7.3
10-11								2		2		5	21	35	29	5	2	7.7
9-10								2	2	3	3	7	26	31	23	3		7.2
8-9										2	5	13	23	44		2		7.2
7-8										5	8	7	30	28	22			7.1
6-7									2	3	11	21	31	24	8			6.6
5-6								1	4	10	9	25	25	19	7			6.2
4-5							1	1	3	9	15	20	26	20	5	1		6.1
3-4					3	2	2	2	11	6	25	23	14	8	5			5.0
2.5-3.0		1				1		10	7	7	16	10	11	15	15	4	3	6.1
2.0-2.5			1			4	3	3	3	6	12	13	9	18	19	9		6.5
1.5-2.0		1		1			1	1		10	9	11	9	19	28	8	1	7.0
1.0-1.5		1		1		1	1		2	5	1	2	11	25	31	11	6	7.8
0.5-1.0								2		3	2		5	17	34	25	14	9.0

between the horizontal lines of adjacent levels corresponds to 50 per cent. Percentage frequencies of lapse-rates greater than 10°C/gkm. are plotted against 10°·5 abscissa, (9·1 to 10) C/gkm. against 9°·5,.........(-5·0 to -4·0)°C/gkm. against -4°·5, and lapse-rates less than -5°C/gkm. against -5°·5, respectively. The thick dots represent the seasonal mean lapse-rates. The figure brings out clearly the following points:—

(1) The large scatter of lapse-rates above 8 gkms. and below 4 gkms. in the winter months and the comparative steadiness of lapse-rate between these two levels.

(2) The sharp decrease of lapse-rate above 3 to 4 gkms. in the summer months and the large scatter of lapse-rates between 10 and 14 gkms. in these months.

(3) The progressive increase and remarkable steadiness of lapse-rates between 6 and 14 gkms. in the monsoon months.

(4) The nature of the transition from the monsoon to the winter conditions which is accompanied by a displacement of the lapse-rate frequencies towards lower values above 10 gkms. and towards higher values below that level.

5. Inversions and Isothermals

Records of sounding balloon meteorographs often show the existence in the troposphere of regions where the temperature instead of decreasing with height either remains constant (isothermal) or increases (inversion). If inversions and isothermals occur at random, their effect will be to cause a general decrease of lapse-rate at all levels when the results of a large number of ascents are averaged. On the other hand, if they occur more frequently at certain levels than at others, then the mean height-lapse-rate curve would exhibit fairly sharp changes of lapse-rate at these levels. In the preceding section, we have already drawn attention to the fact that sharp and sudden changes both in the mean lapse-rate as well as in the frequency distribution occur at certain levels which are not the same in all the months. In the departmental publications of sounding balloon data already referred to, the levels at which changes of lapse-rate occur including the thickness of the layers in the case of inversions and isothermals, and the magnitude of the temperature changes in the case of inversions are separately given. From the published data, the inversions and isothermals observed in each gkm. layer from the surface up to 15 gkms. were tabulated for each month for all the ascents during the ten-year period under discussion. Using the number of observations at each level given in Table 1 (b), the percentage frequencies of occurrence of inversions and isothermals in the various gkm. steps were worked out for all the months, January to December. The results are given in Table XIX.

Records Inversions

TABLE XIX

Percentage Frequencies of Inversions and Isothermals over Agra.

Layer (Gkm.)	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
14-15	19	[illegible]	18	33	30	3	3			12	47	23
13-14	22	26	21	25	26					12	43	31
12-13	25	20	18	23	20	3				2	16	11
11-12	27	17	18	36	6	8					10	20
10-11	12	20	45	36	31	5				2	3	17
9-10	7	18	10	11	[illegible]	5				5	10	6
8-9	7	11	20	7	3	8	8			7	7	5
7-8	8	4		5	9	14	3			11	7	8
6-7	5	10	12	5	11	30	5	6	10	16	6	
5-6	9	10	12	21	32	40	7	6	37	16	3	10
4-5	22	13	22	27	21	28	23	16	16	27	8	10
3-4	30	17	24	16	8	17	14	11	27	46	25	12
2-3	21	13	17	7	3	6	22	17	32	33	25	25
1-2	55	40	7		13	8	13	11	10	7	42	50
Surface—1·0	25	28	7	7	5	12	5	4	5		6	27

The table shows that the inversions and isothermals in the troposphere over Agra may be broadly divided into two classes. The first system confined to the lower half of the troposphere (up to about 7 gkms.) is present in all the months of the year. The second system confined to the upper half of the troposphere (7-15 gkms.) is observed during the months October to May, but is completely absent in the monsoon months.

In November, December, January and February, inversions of the first class are most frequent between 1 and 2 gkms. We have already seen that in these months the mean lapse-rates are minimum in this layer and also that the individual lapse-rates show large scatter. In March, the layer of maximum frequency of inversions and isothermals lies between 3 and 4 gkms. in April, between 4 and 5 gkms. and in May and June between 5 and 6 gkms. In July and August, inversions and isothermals are most frequent between 2 and 5 gkms., while in September the layer of maximum frequency lies between 5 and 6 gkms. In the latter month, inversions and isothermals are also quite common between 2 and 4 gkms. In October, the layer of maximum frequency is seen to lie between 3 and 4 gkms. As might be expected, the layers which are characterised by maximum frequency of occurrence of inversions and isothermals generally coincide with the lower minima in the mean height lapse-rate curves. (*Vide* dotted curve in *Fig. 1.*)

Considering the inversions in the upper troposphere, we see that these occur in the months October to June although the frequency in the last month is very much smaller compared with the other months. Inversions of this class are most frequent between 13 and 15 gkms. in October and November, the percentage frequency being much greater in the latter month. From December to May, inversions and isothermals are very common between 10 and 15 gkms. and occur with lesser frequency between 8 and 10 gkms. It is noteworthy that from November to March there is a definite tendency for the inversions and isothermals in the upper troposphere to descend to lower levels and to occur with increasing frequency in the layer between 10 and 11 gkms. In March, April and May, this layer appears to be characterised by the maximum frequency.

Tables XX to XXXI give the inversions and isothermals observed between the surface and 15 gkms. in each month classified according to depth.

It will be seen that the inversions and isothermals of the upper troposphere are generally deeper than those of the lower troposphere. On the aggregate, inversions and isothermals whose depths lie between 0·2 and 0·4 gkms. predominate in all the months.

In general, isothermals are far more common than inversions and this appears to be a natural consequence of the fact that both these are only more and more advanced stages of a local decrease of lapse-rate brought about by one or other of a variety of causes. *Fig. 4* gives isopleths of percentage frequencies of inversions and isothermals over Agra. *Fig. 5* gives the height-temperature diagrams of some selected ascents showing inversions and isothermals.

TABLE XX—JANUARY

Thickness / Layer (Gkm.)	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 Gkm. or more	Total.
14-15		1		1	3	1	1		1	1	1	10
13-14			2	1	3	1	1				4	12
12-13		1	2	1	2	1	1				7	15
11-12			2	3	3	1	1	1	2		3	16
10-11		1		4							2	7
9-10		1	1	1	1							4
8-9			2	1				1				4
7-8		1		2					1	1		5
6-7	1		1	1								3
5-6	1		2	2			1					6
4-5		2	7	4	1				1			15
3-4		2	8	5	3				2			20
2-3	1	3	5	2		2	1					14
1-2		8	9	10	1	2	2	2	1	1	1	37
Surface—1·0	1	6	5	2	1	1					1	17
Total ...	4	26	46	40	18	9	8	4	8	3	19	185

TABLE XXI—FEBRUARY

Thickness / Layer (Gkm.)	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 Gkm. or more	Total.
14-15		1	1		1						1	4
13-14			2		1	2	1	2	1		1	10
12-13		1	1		2	1	1				2	8
11-12				1	1	1		1		2	1	7
10-11	1	1		2					2		3	9
9-10						1	1	2	2		2	8
8-9			1	2						2		5
7-8					2							2
6-7		1	1	2	1							5
5-6		4	1									5
4-5	1	1	4		1							7
3-4		5	2	2								9
2-3	1	2	1	2							1	7
1-2	3	5	6	5	1		1					21
Surface—1·0		3	5	6	1							15
Total ...	6	24	25	22	11	5	4	5	5	4	11	122

Table XXII—March

Thickness / Layer (Gkm.)	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15		2	1	2		2						7
13-14	1		4			1	1		1			8
12-13	1	1	1		1	1		1			1	7
11-12			1		1	1	1		1		2	7
10-11			2	3	5	1	2	2	1		1	17
9-10							1			3		4
8-9	1		2	1	2	1		1				8
7-8												
6-7			1	3						1		5
5-6		2	2	1								5
4-5		5	2		1		1					9
3-4		2	5	2	1							10
2-3		1	4	1	1							7
1-2		1		1		1						3
Surface—1·0		1	1		1							3
Total ...	3	15	26	14	13	8	6	4	3	4	4	100

Table XXIII—April

Thickness / Layer (Gkm.)	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15		2	3	5	2					1		13
13-14			4	2	2		1				1	10
12-13		1	2	1	1	1	1	1			1	9
11-12	1		6	1	3			1			2	14
10-11		1	3	2	3	4			1	1	1	16
9-10		1	2	1								4
8-9		2		1								3
7-8		1					1					2
6-7		1		1								2
5-6	1	4	2	2								9
4-5	2	7	1	1	1							12
3-4			4	2	1							7
2-3		1	1		1							3
1-2												
Surface—1·0		2	1									3
Total ...	4	23	29	19	14	5	3	2	1	2	5	107

Table XXIV—May

Layer (Gkm.) \ Thickness	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15	1		1	1								3
13-14			2	5	1							8
12-13		1	2	1	1	1						6
11-12								1			1	2
10-11		1	2	1	2	4						10
9-10		1		1								2
8-9			1									1
7-8			2			1						3
6-7		2	2									4
5-6	1	3	3		3		1			1		12
4-5		2	2	3	1							8
3-4			2	1								3
2-3			1									1
1-2		1	2	1	1							5
Surface—1·0			1		1							2
Total ...	2	11	23	14	10	6	1	1	...	1	1	70

Table XXV—June

Layer (Gkm.) \ Thickness	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15			1									1
13-14												
12-13		1										1
11-12		1	2									3
10-11		1			1							2
9-10		1	1									2
8-9		1	2									3
7-8			2	1	1		1					5
6-7		2	3	3	3					1		12
5-6		2	4	5		3	1	1	1	1		18
4-5		3	3	2	5							13
3-4		6	1	1								8
2-3			1	1	1							3
1-2		2	1	1								4
Surface—1·0		5	1									6
Total ...	...	25	22	14	11	3	2	1	1	2	...	81

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TABLE XXVI—JULY

Thickness. / Layer (Gkm.)	< 0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm or more.	Total.
14-15					1							1
13-14												
12-13												
11-12												
10-11												
9-10												
8-9			3									3
7-8			1									1
6-7		1		1								2
5-6			1	1	1							3
4-5		3	3	2		1		1				10
3-4		2	2	1	1							6
2-3	1	1	2		2	2	2					10
1-2	2	1	1	1		1						6
Surface—1·0			1				1					2
Total ...	3	8	14	6	5	4	3	1				44

TABLE XXVII—AUGUST

Thickness. / Layer (Gkm.)	< 0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm or more.	Total.
14-15												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7			2	1								3
5-6		1		2								3
4-5			2	2	1			2	1			8
3-4		1	1	3						1		6
2-3		4	2	2	1							9
1-2	1		3	1	1							6
Surface—1·0			1	1								2
Total ...	1	6	11	12	3			2	1	1		37

Table XXVIII—September

Thickness / Layer (Gkm.)	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8												
6-7	1		1	1		1						4
5-6		4	5	2	2			1				14
4-5	1	1	2	2								6
3-4	1	3	1	3		2			1			11
2-3		1	7	3	1	1						13
1-2		2	2									4
Surface—1·0		1	1									2
Total ...	3	12	19	11	3	4		1	1			54

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Table XXIX—October

Thickness / Layer (Gkm.)	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15			2	2					1			5
13-14		2			1	1					1	5
12-13						1						1
11-12												
10-11						1						1
9-10		1	1									2
8-9		1	1	1								3
7-8		1		4								5
6-7	1	1	2		1	2						7
5-6		1	1	3	1		1					7
4-5	2	3	5		1		1					12
3-4		8	3	3	4		2	1				21
2-3		3	4	6		2						15
1-2		3										3
Surface—1·0												
Total ...	3	24	19	19	8	7	4	1	1		1	87

TABLE XXX—NOVEMBER

Layer (Gkm.) \ Thickness	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15			1	2	3	3	2	2			1	14
13-14		1	2	3	3	2	1			1		13
12-13		1	2	1					1			5
11-12					2						1	3
10-11			1									1
9-10			1			1		1				3
8-9			2									2
7-8		1	1									2
6-7		1			1							2
5-6					1							1
4-5		2	1									3
3-4		1	5	1	2							9
2-3		3	2	2		1			1			9
1-2		4	2	4	1	2		1			1	15
Surface—1·0					1		1					2
Total ...		14	20	13	14	9	4	4	2	1	3	84

TABLE XXXI—DECEMBER

Layer (Gkm.) \ Thickness	<0·1	·10 to ·19	·20 to ·29	·30 to ·39	·40 to ·49	·50 to ·59	·60 to ·69	·70 to ·79	·80 to ·89	·90 to ·99	1·0 gkm. or more.	Total.
14-15			2	2	2	1		1				8
13-14			2	2	1	1	1	1	3			11
12-13			1	1				2				4
11-12				3	2	1					1	7
10-11		1	2	1	1		1					6
9-10			1					1				2
8-9					1						1	2
7-8						3						3
6-7												
5-6			2	1						1		4
4-5		2	1						1			4
3-4			1	1		1	1		1			5
2-3		1	3		2	1	1	1			1	10
1-2		2	11	2	2	1	2					20
Surface—1·0		1			2	2	4		1		1	11
Total ...		7	26	13	13	11	10	6	6	1	4	97

6. Mean Monthly Temperatures

In order to get the mean monthly temperatures at standard geodynamic levels, the mean monthly temperatures for 1 gkm. based on the individual ascents were worked out for all the months. Using the lapse-rates given in Table II, the temperatures at all heights from 0·5 to 26 gkms. were then calculated. The results are given in Table XXXII. The annual range of temperature at each level is given in the last column of this table.

TABLE XXXII

Mean Monthly Temperatures over Agra (°A)*

Height (Gkm.)	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Range (Max. – Min.) °C.
26	19·9	21·5				24·6			34·9		25·3	22·2	
25	18·4	20·2		20·2	27·7	32·6		20·5	27·4	21·3	23·8	19·7	
24	16·4	19·2		20·1	25·2	19·9	16·8	19·5	22·7	19·8	20·8	17·4	
23	14·4	16·2	13·0	19·7	21·2	18·2	13·8	18·0	19·0	18·1	17·4	15·6	9·2
22	11·8	14·2	12·4	16·4	18·9	16·4	12·8	14·3	15·6	16·4	13·3	13·3	7·1
21	10·4	10·6	11·3	12·1	14·4	13·5	07·8	10·8	12·1	13·8	09·7	10·1	6·6
20	07·4	07·4	07·8	07·2	08·6	08·7	04·2	06·1	08·7	10·6	04·9	07·5	6·4
19	05·1	05·3	04·5	01·9	03·1	03·0	98·0	01·1	04·4	05·9	01·7	05·2	7·9
18	08·2	02·0	00·9	98·5	98·2	97·8	92·6	95·4	98·0	00·8	99·0	02·6	10·6
17	02·3	01·2	99·8	97·3	96·7	96·1	93·1	93·9	93·1	96·7	97·7	01·5	9·2
16	02·7	02·6	01·7	99·8	99·0	97·7	96·9	95·8	94·2	97·1	98·9	01·9	8·5
15	05·2	05·9	04·9	04·0	04·3	04·4	04·1	02·0	00·8	01·1	01·9	04·1	5·1
14	08·8	09·4	10·0	09·5	10·3	12·4	12·8	10·7	09·2	07·4	06·2	07·3	6·6
13	12·5	13·6	15·2	14·4	17·3	20·9	22·2	19·9	18·4	14·8	12·0	11·4	10·8
12	16·3	17·9	20·4	19·3	24·0	29·4	31·2	29·0	27·1	22·4	18·6	17·2	14·9
11	21·7	23·0	25·8	24·4	30·8	37·7	39·7	37·7	35·5	30·1	25·3	23·5	18·0
10	28·5	28·4	31·0	30·8	37·5	45·4	47·7	46·0	43·3	37·9	32·9	30·2	19·3
9	35·7	34·7	37·6	38·8	44·7	52·7	54·6	53·4	50·7	45·2	39·9	37·3	19·9
8	42·7	41·7	44·1	46·7	51·5	59·2	61·0	60·2	57·9	52·3	47·3	44·4	19·3
7	49·6	49·0	51·0	54·3	58·5	65·2	66·7	66·2	64·2	59·1	54·7	51·4	17·7
6	56·7	56·1	58·0	61·7	65·1	70·1	72·2	71·7	69·8	65·4	61·6	58·6	16·1
5	63·6	63·9	64·8	68·7	71·2	74·5	77·1	76·7	74·7	71·0	68·5	65·0	14·2
4	69·8	69·1	72·0	75·7	78·0	80·5	82·5	82·1	80·0	76·7	75·2	71·5	13·4
3	76·0	75·4	79·4	83·3	86·2	87·4	87·3	86·9	85·2	81·6	80·4	77·3	12·0
2·5	79·0	78·5	83·0	87·6	90·6	91·1	89·8	89·1	87·9	84·8	83·2	80·0	12·6
2·0	81·7	81·8	87·2	92·1	95·0	94·9	92·7	91·6	90·8	88·5	85·8	82·4	13·3
1·5	84·0	84·9	91·4	96·5	99·2	98·7	95·4	94·3	93·9	92·6	88·6	84·8	15·2
1·0	86·5	88·2	95·9	01·0	03·3	02·8	98·9	97·4	97·5	96·9	91·9	86·9	16·8
0·5	90·3	92·2	00·4	05·5	07·8	06·6	02·4	00·9	01·8	01·4	96·5	90·4	17·5

* The hundreds figure has been omitted in all cases.

Up to 2 gkms. January is the coldest month; between 2 and 10 gkms., the lowest temperatures occur in February, while between 10 and 14 gkms. the mean temperatures have minimum values in January, December or November. Above 14 gkms. and up to 21 gkms. temperatures are lowest in July or September. Above 21 gkms., the numbers of observations in the individual months are far from being comparable and so it is not possible to draw definite conclusions. Up to 2 gkms., the maximum temperatures occur in the month of May, between 2 and 3 gkms. in June and above this up to 14 gkms. in the month of July. Between 14 and 18 gkms., January or February appears to be the hottest month and above that October or May.

The annual range of temperature decreases from the surface to 3 gkms., above which it progressively increases to a maximum at 9 gkms. Above 12 gkms., there is a sudden drop in the annual range of temperature, but there is a secondary maximum at 18 gkms. *Fig. 6* gives the annual variation and the annual range of temperature up to 23 gkms over Agra.

7. Tropopause

It is difficult to give a strict definition of tropopause which will cover all the different types of transition from the troposphere to the stratosphere actually met with. In the departmental publications of sounding balloon data, the usual types met with in India are classified under four major heads and designated as Types I, II III and IV. Ramanathan and Ramakrishnan[2] have drawn attention to certain limitations of this classification and have suggested an alternative method. For the discussion of mean monthly conditions we might consider two heights, one above which the lapse-rate is less than 2°C gkm. and the other above which the lapse-rate is negative. If we denote these two heights by Hc1 and Hc2 and the corresponding temperatures by Tc1 and Tc2, then the values of these quantities for the different months are as given in the following table:

TABLE XXXIII

Month.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Hc_2 (gkm.)	16·7	17·1	17·3	17·2	17·1	17·0	17·6	17·0	16·7	16·5	17·0	16·7
Tc_2 (°A)	202·8	201·2	199·8	197·3	196·8	195·1	192·2	193·9	193·0	196·4	197·7	201·4
Hc_1 (gkm)	15·7	16·3	16·3	16·7	16·5	16·6	17·0	16·5	16·1	16·2	16·0	15·7
Tc_1 (°A)	203·3	202·0	201·0	197·9	197·4	195·6	193·1	194·2	193·3	196·8	198·7	202·3

The values of Hc1 and Hc2 have been picked out from the mean monthly height-lapse-rate diagrams given in *Fig. 1.* The figure shows that both Hc1 and Hc2 lie on a part of the curve which is nearly linear, i.e., in a region in which the lapse-rate decreases uniformly with height. There are, however, certain levels in the upper troposphere at which there is a sharp decrease of lapse-rate with height. The approximate heights (H) of these levels as obtained from *Fig. 1* are given in Table XXXIV below.

TABLE XXXIV

Month	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
H	10	9	10	10	14	14	14	14	14	11	11	10
(gkm.)	15	16	15	15	16					14	15	18

8. Discussion

The geographical situation of Agra (Lat. 27°08′ N., Long. 78°01′ E.) as well as the fact that practically all the sounding balloon ascents considered in the present paper were made generally between 17 and 19 hrs. have to be borne in mind in order to understand the variations in the thermal structure of the atmosphere over the station from month to month. In the winter months, the station comes under the influence of the vast Asiatic anticyclone in the lower layers and the temperate latitude westerly circulation in the upper layers. With the advance of summer and the shifting of the thermal equator towards the north, solar radiation becomes more and more abundant. Consequently surface temperatures become very high over Northwest India and adjoining areas and these regions gradually become the seat of the lowest pressure in the world. Conditions are thus rendered favourable for the onset of the southwest monsoon which breaks over the south of the peninsula by about the end of May, and extending slowly northwards holds its sway over the country for the whole of July and August giving copious rainfall. The monsoon begins to withdraw from the country in September and by the end of this month the whole of northwest India and the United Provinces is well outside the influence of the monsoon current. In October, the monsoon retreats further south and pressure gradients are generally weak over the country. Thereafter, winter conditions set in with pressure decreasing from north to south.

We shall now consider the significance of the seasonal variations in the thermal structure of the atmosphere over Agra described in the preceding sections.

(a) *Lower Troposphere (Surface to 7 gkms.)*.—During the months November to February, both the duration and the intensity of solar radiation are the lowest and the effects of ground heating do not extend above 1 gkm. The large number of inversions and isothermals in the lower troposphere in these months with maximum frequency between 1 and 2 gkms. appear to result primarily from the subsidence of air from higher levels. It is well known[3] that when an air mass with stable lapse-rate subsides, its lapse-rate tends to recede more and more from the dry adiabatic lapse-rate and the diminution of lapse-rate is accentuated, when subsidence is accompanied by horizontal divergence. Thus if a sample of air with a lapse-rate of 6°C gkm. descends from 600 mbs. to 800 mbs. its lapse-rate would be reduced to 4·7°C gkm. if there is no horizontal divergence. If in the process the sample of air under consideration spreads out over an area of twice its original cross section, then instead of the original lapse-rate of 6°C gkm. an inversion of 0·7°C gkm. would result.

An examination of the humidity values recorded by the sounding balloon ascents shows that in a number of cases where inversions and isothermals are observed in the months of November to February, there is a rapid decrease of relative humidity between 1 and 3 gkms. The inversions and isothermals are observed in both clear and cloudy weather.

Besides subsidence and divergence, many other factors, such as turbulence, variations in the moisture content of air with height and radiation, can give rise to sharp decrease in lapse-rates or inversions.

From February to March, there is a rapid increase in the surface temperature at Agra. There is a corresponding increase in the lapse-rates up to 2·5 gkms. which presumably marks the limit to which thermal convection and turbulence extend during the afternoons in this month.

The net upward flux of heat per unit area in the atmosphere due to eddies is given by $-K\rho C_v\left(\frac{dT}{dz}+\Gamma\right)$ where $\frac{dT}{dz}$ is the prevailing lapse-rate and Γ is the dry adiabatic lapse-rate[4]. This expression shows that when the existing lapse-rate is less than Γ, eddy transfer of heat in the atmosphere will be downwards and we should expect a fall of temperature at the top of the column affected by turbulence. This appears to be the explanation of the inversions and isothermals between 3 and 5 gkms. in March, which are particularly well marked on clear days.

Surface temperatures continue to rise in April and May and there is a corresponding increase in the depth of the lower layer with high lapse-rates. In April and May, this layer extends to 4 gkms. and the next two gkms. are characterised by the largest number of inversions and isothermals. On account of the high lapse-rates in the lower layers, it is clear that very little energy is required for the vertical transport of air through the lower layers of the atmosphere, and conditions are very favourable for the occurrence of convective phenomena such as duststorms and thunderstorms. Along with the rise in temperature, there is a progressive increase in the moisture content of the atmosphere, and clouding and thunderstorms increase with the advance of summer. While the inversions and isothermals which are most frequent between 4 and 6 gkms. in April and May generally mark the limit of convection and turbulence in these months, it is probable that some of the inversions and isothermals observed at lower levels in May are associated with cloud tops.

From May to June, there is a fall in temperatures up to 2·0 gkms. as well as a decrease of lapse-rate at all levels in the lower troposphere. Results of sounding balloon ascents show a large increase in the moisture content of atmosphere from May to June at all levels. The frequency of thunderstorms also shows a corresponding increase[5]. As has been pointed out by Ramanathan[6], the fall in temperature of the lower layers is caused by cooling due to the thunderstorm rains and the latent heat liberated above the level of condensation is responsible for the rapid increase of temperature in June above 2·0 gkms. as compared with May. The marked lapse-rate minimum between 5 and 6 gkms. and the large number of inversions and isothermals between 4 and 7 gkms. again appear to mark the limit to which turbulence brought about by insolation extends in this month.

Since the effect of turbulence is in general to cause intermixing of the air between lower and higher levels, we should expect to find an increase of relative humidity from the surface to the top of the layer affected by turbulence and a sudden decrease of relative humidity above that height. This will be readily understood when it is remembered that in an air mass which is completely churned up, humidity mixing ratio will not vary with height so long as there is no condensation, whereas the decrease of temperature at the dry adiabatic lapse-rate would cause the relative humidity to increase with height. Mean monthly relative humidities over Agra in the month of June show a gradual increase with height up to 5 gkms. above which there is a sudden decrease of relative humidity. It is well known that conditions of stability demand a sharp decrease of lapse-rate or even an inversion at the interface between two air masses of which the lower one has the higher moisture content. It is, therefore, probable that the sharp decrease of lapse-rate above 5 gkms. in June is often accentuated by sharp humidity discontinuities at this level.

In this connection the results of aeroplane ascents made at Peshawar, Lahore and Ambala in the months of May and June are of interest. These ascents which were generally made in the early mornings show on many days that above a ground inversion of small depth, lapse-rates approach the dry adiabatic value up to about 5 gkms. and show a sharp decrease at that height. Above the level of ground inversions and up to the level where the decrease of lapse-rate sets in, the S. T. grams practically follow the saturation adiabat (*vide Fig. 7*). This type of structure which is presumably typical of the whole of northwest India in the summer months is the result of thorough mixing of the lower atmosphere brought about by turbulence in the summer afternoons. The effect of ground cooling by radiation at night is propagated only to a very small height whereas the effect of ground heating affects a considerable depth of the lower atmosphere. Consequently the high lapse-rates in the lower layers are observed even in the early morning above the shallow layer of ground inversion.

The inversions and isothermals observed in the lower troposphere during the monsoon months of July and August can be due to humidity discontinuities, turbulence or radiation. There appear to be two layers of maximum frequency of inversions and isothermals in this month, one between 2 and 3 gkms. and the other between 4 and 5 gkms. Low, medium and high clouds in varying amounts were present on practically all the days of sounding balloon ascents in these months. 245

In September, there is a decrease of relative humidity above 5 gkms. and this is perhaps one of the reasons for the sudden decrease of lapse-rate and for the large number of inversions and isothermals between 5 and 6 gkms in this month. It is also probable that anticyclonic subsidence, characteristic of the winter months, has already set in at higher levels in September and slowly descends to lower levels in October.

In October, on account of the decreased clouding consequent on the withdrawal of the monsoon, surface temperatures are slightly higher than in the previous month and lapse-rates increase in the lower levels up to 3 gkms. The sudden decrease of lapse-rate at this level and the large number of inversions and isothermals at and above this height

are presumably due to turbulence in the lower layer and anticyclonic subsidence in the upper layer heralding winter conditions.

(*b*) *Upper Troposphere (7 to 15 gkms.).*—The sudden decrease of lapse-rate (very often an inversion or isothermal extending sometimes over a depth of one to two gkms.) near about 12 gkms. shown by the records of sounding balloon ascents at Agra during the months November to May has been recognised to be in the nature of a transition from the troposphere to the stratosphere. Above this there is, in general, again a layer of decreasing temperatures terminating invariably in an inversion at about 17 gkms. In the departmental publication of sounding balloon data, this type of double transition from the troposphere to the stratosphere is designated as tropopause of type IV. Ramanathan and Ramkrishnan[7] have pointed out that this type of structure in a less conspicuous form is also shown by the records of sounding balloons let off from Poona (Lat. 18°32′ N., Long. 73°51′ E.) during the months November to April.

In a note published in *Nature*[8] Ramanathan and Ramkrishnan explained this type of structure as being brought about by the meridional advection of air in the upper troposphere. According to them, the air above 12 gkms. over tropical latitudes which is colder than the air at the same level over higher latitudes tends to spread towards higher latitudes and to compensate for this an opposite movement of air from higher to lower latitudes takes place below this level. According to this picture, the tropopause in temperate latitudes will have a "folded structure" and will show a double transition from the troposphere to the stratosphere, the lower transition corresponding to the tropopause of higher latitudes and the upper one to that of lower latitudes. Venkiteshwaran[9] and Chiplonkar[10] have also considered some aspects of this question.

While meridional advection does give a plausible explanation for the double transition, it does not by itself provide an answer as to why the lapse-rates above the lower transition are only of the order of 3° to 5°C/gkm. while the tropical troposhere is characterised by high lapse-rates (8° to 10°C/gkm.) between 10 and 15 gkms. It is also a fact of observation that the inversions which characterise the transition from the troposphere to the stratosphere in the tropics are very much more pronounced than the corresponding inversions observed in the non-monsoon months over Agra. An examination of Tables II to XIV of the present paper brings out that if we exclude the lower levels affected by thermal convection and turbulence, the highest lapse-rates in the troposphere over Agra in the months November to April occur between 7 and 11 gkms. One of the most striking changes that follows the retreat of the monsoon in September from northwest India and the west United Provinces is a fall in the lapse-rates above 10 gkms. and an increase in the lapse-rates for the next few gkms. below this level. While the lapse-rates between 6 and 10 gkms remain more or less constant during the months November to May, we see that there is a progressive decrease in the lapse-rates above 11 gkms. from October to January, a slight increase from January to April and a more pronounced increase from April to May. Between 6 and 15 gkms., the lapse-rates practically follow the saturation adiabat in the months June to September. The monthly distribution of rainfall and the number of rainy days (N) at

Agra in the different months of the year are of interest in this connection and are given in the table below: —

Month.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
Rainfall (in.) .	0·54	0·48	0·35	0·24	0·47	2·35	9·02	9·95	4·05	0·96	0·12	0·27
N ...	1·3	1·0	1·0	0·7	1·4	3·8	11·4	10·2	5·4	0·8	0·3	0·7

During the months June to September, the trend of lapse-rates in the middle and upper troposphere over Agra suggests that the condensation of water vapour is by far the most important factor controlling the lapse-rates at these levels. The question naturally arises, what is the effect of cutting off this source of heat supply as actually happens when the monsoon withdraws from northwest India and west United Provinces in September?

Some years ago F. Albrecht[11] drew attention to a result of fundamental importance that follows from a consideration of the flux of long-wave radiation at different heights in the atmosphere. He found that practically the entire contribution to the outward radiation to space from the atmosphere comes from a layer in the upper troposphere between heights corresponding to effective water vapour contents of 0·1 gm/m^3 and 0·01 gm/m^3. According to Albrecht, when the atmosphere is highly humid this "*Emission Layer*" lies roughly between heights corresponding to 233°A and 213°A and when the moisture content of the atmosphere is small between 243°A and 223°A.

For mean annual conditions, Albrecht's emission layer lies between 5 and 9 gkms. at the poles; the height of the layer increases as we proceed towards lower latitudes and at the equator it lies between 9 and 12 gkms. According to Albrecht, the top of the emission layer marks the limit of the troposphere in polar and temperate latitudes. In the tropics, the strong vertical convection currents penetrate the emission layer so that the tropopause lies appreciably above the top of this layer. Consequently, as has been pointed out by Bjerknes,[12] the top of the tropical troposphere is cooled below the temperature corresponding to radiative equilibrium with the result that it absorbs more radiant energy from the lower layers of the stratosphere than it emits. This results in a cooling of the lower layers of the tropical stratosphere below the radiative equilibrium temperature, the magnitude of the cooling decreasing rapidly with height above the tropopause. The temperatures in the lower stratosphere in the tropics do not therefore correspond to conditions of radiative equilibrium. Only at a height of about 26 gkms. does the tropical stratosphere attain the unperturbed radiative equilibrium temperature. This picture of the transition from the troposphere to the stratosphere in the tropics gives a natural explanation of the rapid increase of temperature for the first few gkms. above the tropopause in the tropics.

One of the most interesting consequences that follows from Albrecht's work is that the absence of any external source of heat supply would result in a direct cooling of the middle and upper troposphere by radiation leading to a diminution of lapse rate in the upper troposphere and an increase in the middle troposphere. As has been pointed out by Brunt,[13] there should, on this account, be a very definite difference in the vertical temperature distribution in regions of condensation and those of continued clear weather.

Over Agra, the thermal structure of the atmosphere in the months June to September is practically identical to that observed in the tropics. The latent heat of condensation is the most important source of heat supply to the atmosphere in these months. With the retreat of the monsoon in September, this source of heat supply is cut off and solar radiation also becomes less and less abundant. We should, therefore, expect to find the effects of radiative cooling of the atmosphere to manifest themselves more and more prominently. If we assume that the emission layer lies between 213°A and 233°A in the months June to September and between 223°A and 243°A in the months November to April, then the position of the layer will be roughly between 11 to 14 gkms. in the former months and between 8 and 11 gkms. in the latter. We shall now examine the changes which we should expect to find in the thermal structure of the upper troposphere *as a result of radiative cooling only,* following the retreat of the monsoon.

The radiative cooling of the emission layer between 11 and 14 gkms. would slowly begin to assert itself and at the same time this layer would tend to descend because of the decrease in the moisture content of the atmosphere. The emission layer would give rise to downward convection which would tend to set up high lapse-rates in and below the layer. Since the cooling decreases very rapidly above the emission layer, the top of the layer will be characterised by a sudden decrease of lapse-rate or an inversion. Absence of penetrative convection from below would tend to restore conditions of radiative equilibrium above the emission layer, i.e. a decrease in the rate of fall of temperature above the layer and in the rate of rise of temperature in the lower stratosphere. In short, the atmosphere would tend to pass over to a condition in which the top of the emission layer forms the upper limit of the troposphere. That the tropical stratosphere and substratosphere when left to themselves under the sole action of radiation without further supplies of moisture from below would tend to get to the condition of those of temperate latitudes has also been pointed out by Dr. Ramanathan[14]. It is clear that all disturbing factors which cause a change in the heat and moisture content of the atmosphere will tend to distort and modify the purely radiational effects outlined above so that the actually observed thermal structure will be some sort of equilibrium condition.

An examination of Tables II to XXVIII suggests that radiation plays a very important role in bringing about the progressive changes in the thermal structure of the upper troposphere over Agra. In the months June to September, the lapse-rate decreases above 14 gkms. (top of the emission layer) and changes sign above 17 gkms. Between these two levels, convection tends to establish dry-adiabatic lapse-rate while radiation tends to establish nearly isothermal conditions. The rapid decrease of lapse-rate with height in the first 3 or 4 gkms. of the lower stratosphere shows the increasing control exercised by radiation with increasing height above the top of the emission layer. The tendency for super-adiabatic lapse-rates in the upper troposphere between 11 and 14 gkms. (emission layer) is noteworthy. Convection tends to establish practically dry adiabatic lapse-rate in this layer; the radiative cooling of the emission layer which is continually in action operates in a manner such as to cause an increasing cooling effect from the base on the top of the column. It is clear that if an air column with dry

adiabatic lapse-rate is cooled continually by progressively increasing amounts from bottom to top, super-adiabatic lapse-rates can be temporarily established in it.

Table XXXII and *Fig. 6* show that after September there is a fall of temperature in the troposphere over Agra below 14 gkms. and a rise of temperature in the upper troposphere and lower stratosphere. These features are essentially connected with the retreat of the monsoon and with it the cutting off of the most important source of heat supply, viz., condensation of water vapour which is also the primary agency responsible for the penetrative convection extending throughout the troposphere in the months June to September. We also notice the extremely interesting and significant result that between 15 and 19 gkms. there is almost a complete reversal of seasons over Agra, the winter months being the warmest. This is presumably due to the partial restoration of conditions of radiative equilibrium in this layer following the retreat of the monsoon. Table XXXII shows that the annual range of temperature over Agra shows a double maximum, one between 7 and 11 gkms. and the other between 17 and 19 gkms. Starting with the thermal conditions obtaining in the monsoon months, we can interpret the first of these as the layer of maximum cooling and the second as the layer of maximum heating in the winter months. The former coincides with the emission layer in the non-monsoon months and the latter is the layer of maximum deviation from radiative equilibrium in the monsoon months.

It is interesting to note that the decrease of lapse-rate, inversions and isothermals in the upper troposphere set in first above 14 gkms. and descend to about 10 gkms. Equally significant is the tendency for the downward march of the region of high lapse-rates in the upper troposphere beginning from September. *Both these facts as well as the features mentioned in the preceding paragraph appear to furnish direct evidence of the existence of the emission layer and the seasonal variation of its altitude depending upon the moisture content of the atmosphere.* Indeed, under the action solely of radiation, the tropopause over Agra during the months November to April should be reached at a height of about 11 gkms. with practically isothermal conditions above that height. In fact, records of some soundings over Agra in the winter months do show this type of thermal structure (*vide Fig. 5*, dated 7th January 1938). The more common structure is, however, a sudden decrease of lapse-rate (often an inversion or isothermal) at about 11 gkms. and a layer of small lapse-rates above that height merging gradually into an inversion at about 17 gkms. This type of "composite" tropopause is to be explained as a combined effect of advection and radiation, the latter tending to establish nearly isothermal conditions in the air with high lapse-rates moving from the low towards high latitudes above the level of the tropopause of high latitudes as pictured by Ramanathan and Ramakrishnan. The persistence of this structure in a more or less conspicuous form during the entire period November to April and its sudden disappearance in June would appear to emphasise the important role played by the radiative cooling of the atmosphere in maintaining the stability of this type of structure. The remarkable changes from April to May and from May to June signify the increasing control exercised by the latent heat of condensation.

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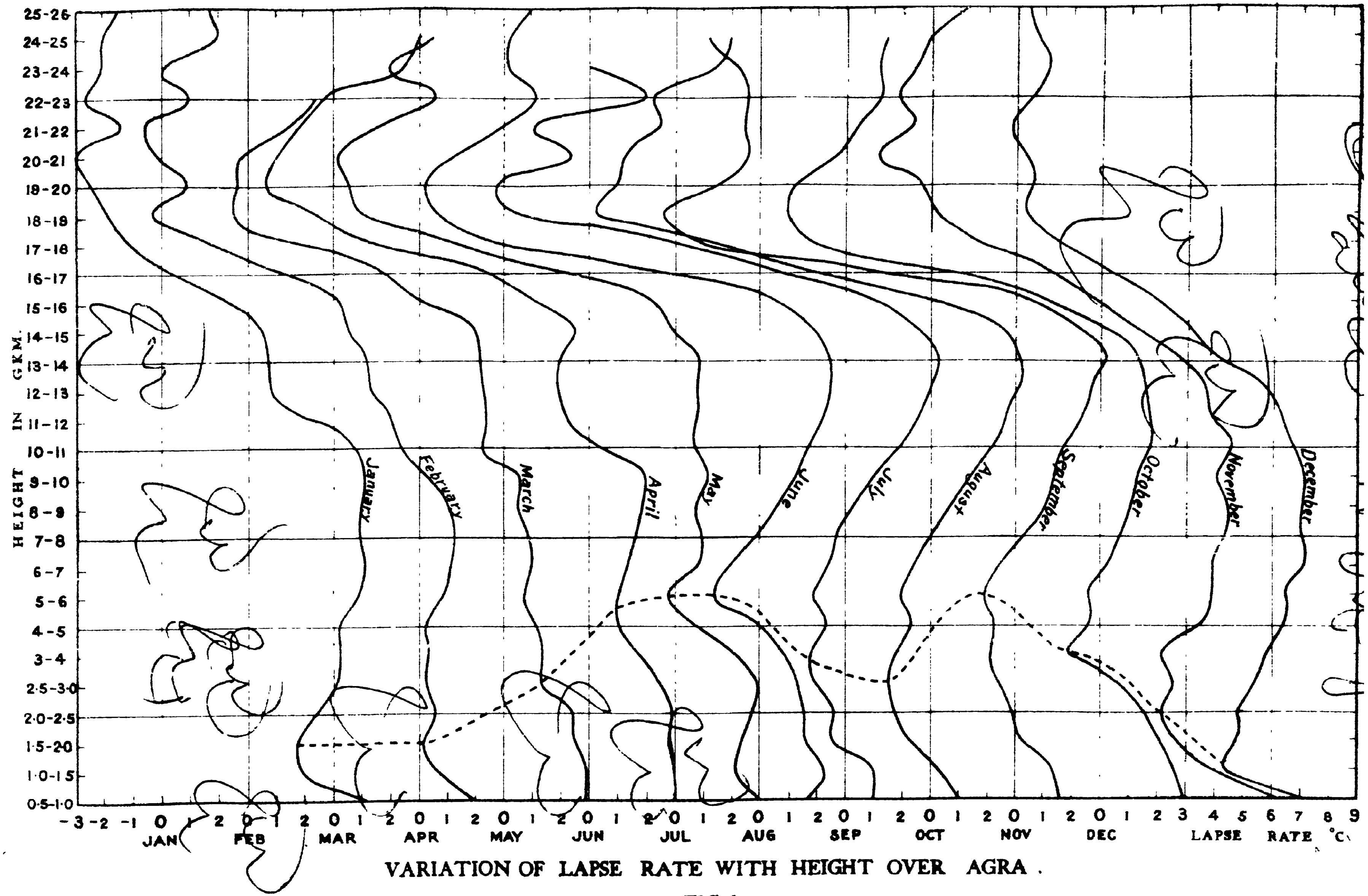
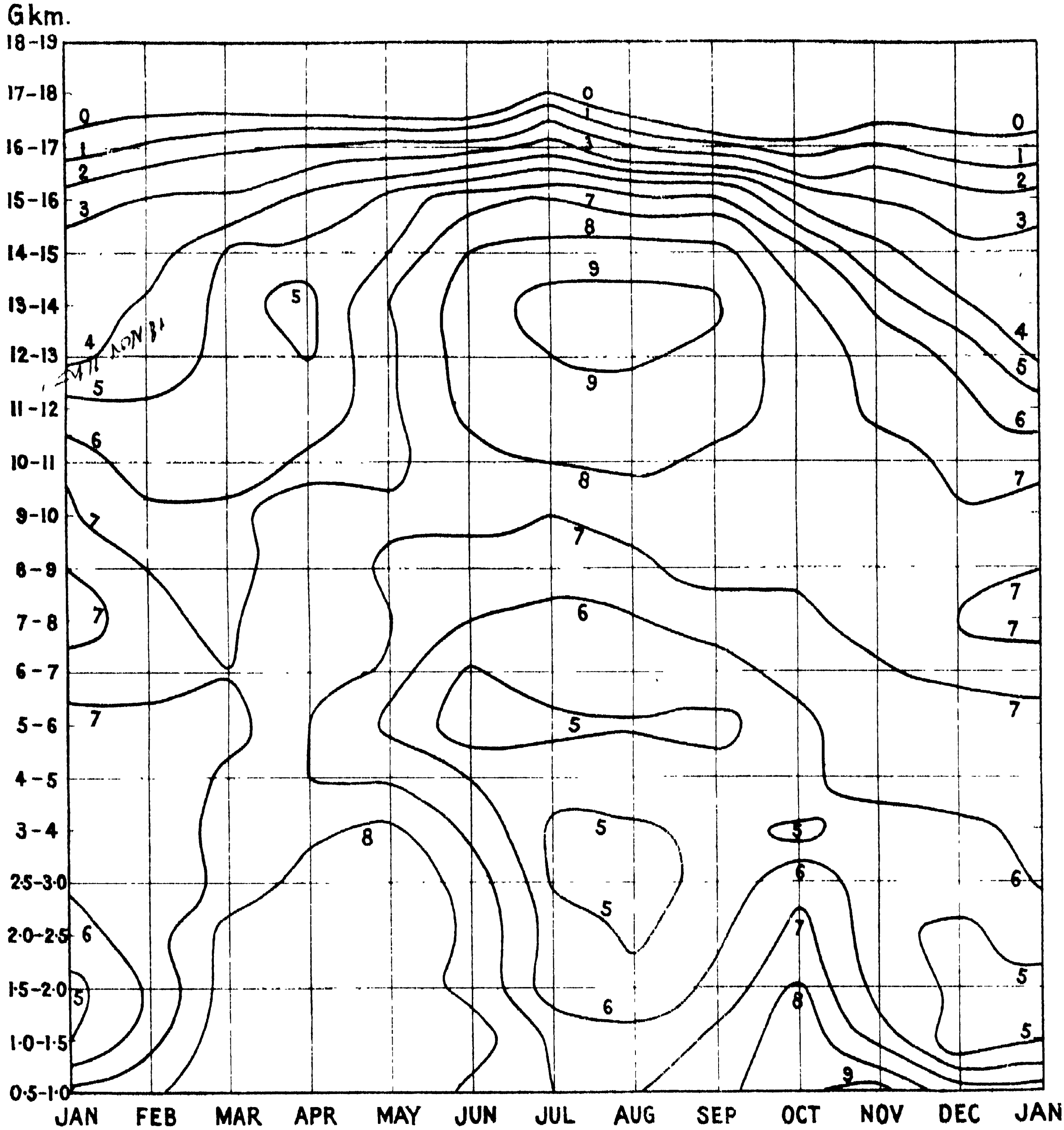
REFERENCES

1. K. R. Ramanathan, *Mem. Ind. Met. Dept.*, **25**, 163 (1930).
2. K. R. Ramanathan and K. P. Ramakrishnan, *Mem. Ind. Met. Dept.*, **26**, 58 (1934).
3. D. Brunt, *Physical and Dynamical Meteorology* (1939), 44-45.
4. D. Brunt, *Loc. cit.*, 226.
5. Ind. Met. Dept., *Sci. Notes*, **I**, 51.
   See also,
   B. N. Sreenivasiah and N. K. Sur, *Mem. Ind. Met. Dept.*, **27**, 2 (1939).
6. K. R. Ramanathan, *Mem. Ind. Met. Dept.*, **25**, 167 (1930).
7. K. R. Ramanathan and K. P. Ramkrishnan, *Mem. Ind. Met. Dept.*, **26**, 58 (1934).
8. K. R. Ramnathan and K. P. Ramakrishnan, *Nature*, **132**, 932 (1933).
9. S. P. Venkiteshwaran, *Ind. Met. Dept. Sci. Notes*, **7**, 59 (1937).
10. M. W. Chiplonkar, *Curr. Sci.*, **4**, 232 (1935).
11. F. Albrecht, *Zeit. f. Geophysik*, **6**, 420 (1930).
    F. Albrecht, *Met. Zeit*, **48**, 57 (1931)
    See also
    F. Moller and R. Mügge, *Zeit. f. Geophys.*, **8**, 53 (1932).
    F. Moller and R. Mügge, *Met. Zeit.*, **49**, 95 (1932).
12. V. Bjerknes and others, *Physikalische Hydrodynamik*, 663-668 (1933).
13. D. Brunt, *Loc. cit.*, 158-159.
14. K. R. Ramanathan, *Biet. z. Phys. d. frie. Atmos.*, **18**, 196 (1932).



VARIATION OF LAPSE RATE WITH HEIGHT OVER AGRA.

FIG. 1.



Isopleths of mean monthly lapse rate over Agra .

FIG. 2.

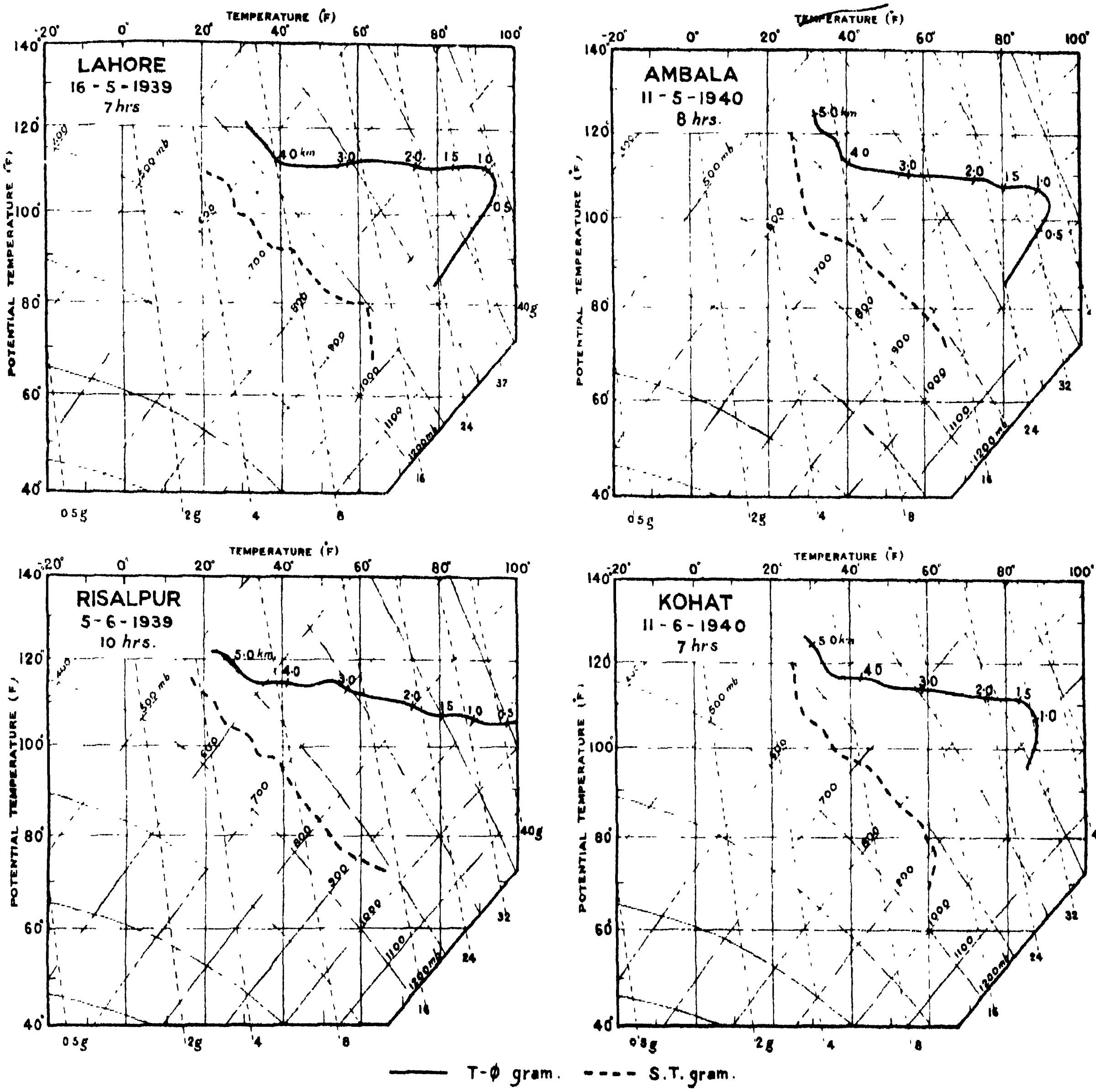

LAHORE
16 - 5 - 1939
7 hrs
AMBALA
11 - 5 - 1940
8 hrs.
RISALPUR
5 - 6 - 1939
10 hrs.
KOHAT
11 - 6 - 1940
7 hrs
TEMPERATURE (°F)
POTENTIAL TEMPERATURE (°F)
T-φ gram. ---- S.T. gram.

FIG. 7.